Mixing in Haro Strait

David Farmer, Institute of Ocean Sciences
9860 West Saanich Road, Sidney, BC, V8L 4B2
(250) 363-6591, Fax: 363-6798, email: dmf@ios.bc.ca
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LONG-TERM GOALS

The long-term goal is to better understand mixing processes in estuaries. Of particular interest are the processes at work in the Haro Strait region between Washington State and British Columbia, which are modulated by a spring/neap cycle in tidal velocities.

OBJECTIVES

The field phase of the Haro Strait experiment took place in the summer of 1996 and involved a collaborative effort between MIT, WHOI and IOS. Our objectives are to understand the dynamics associated with intense coastal mixing processes in which separation of tidal flows past topography leads to formation of fronts accompanied by instability and mixing.

During this year, we have begun to analyze this data in two different areas. First, we wanted to better quantify the large-scale dynamics. This means estimating horizontal layer transports, rates and amounts of mixing that take place. Second, we want to use these results to understand the importance of smaller-scale mixing that occurs at convergence fronts within this region.

APPROACH

The first task after the cruise was to organize and calibrate the large quantities of acoustic and hydrographic data collected by the IOS group. Most of the dataset was then archived onto CD-ROMs to allow for easy distribution among co-investigators. A cruise report containing information about deployments and instrument logs, as well as summarizing preliminary results was written by Rich Pawlowicz, a post-doc working on this project. At this point Pawlowicz left to take up a position at the University of British Columbia. However, he remains closely linked with the analysis, with further assistance of Kevin Bartlett at IOS. The initial effort was concentrated on understanding the larger-scale picture, and a theory has been developed by which CTD observations could be used to infer bulk mixing properties and transports using both heat and salinity as tracers. A second part of the analysis has proceeded to try and advance our grasp of the frontal mixing datasets by combining many disparate observations in an animation. This is proving particularly useful in attempts to integrate autonomous underwater vehicle (AUV) data with SEASCAN drifter and side-scan sonar data. The third part of the analysis component is being carried out by Rizhong Jiang who, in association with Farmer and Pawlowicz is seeking an interpretation of the active frontal process in terms of the underlying dynamics.

WORK COMPLETED

Following completion of processing and archiving of all data on CD-ROM, animation programs have been developed to allow visual comprehension of the frontal features and their time evolution.

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Integration of SEASCAN drifter images generated by sidescan sonar, with AUV data has now been completed to the extent permitted by the data. Estimates have been made of total mixing and transport through the Strait, as well as their changes through the spring/neap cycle. A theoretical treatment for the diagnostic analysis of two layer flow in a strait has been developed (Pawlowicz & Farmer, 1998), through which transports of heat and salt between the layers and heat exchange through the upper boundary may be used to interpret observations. This has been applied to the Haro Strait data. Detailed analysis has begun on the dynamics of the mixing front, with effort focused on the bulk properties of the shear and density gradients. A conceptual model has been developed of the evolution and tilting of the front.

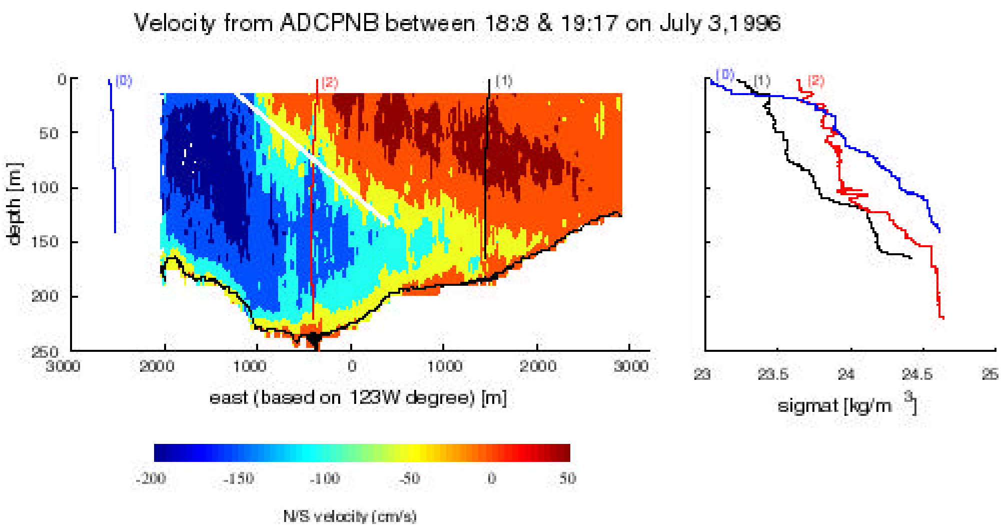

Figure 1: Velocity field within a tidal separation front. The flow speed color contour is of a slice perpendicular to the front: red indicates water moving north, blue is water moving south. The bulk Richardson number calculated from the ADCP velocity measurements, from CTD profiles and from the depth of the shear zone separating the two layers (see white line superimposed) supports the concept of shear flow instability in the vicinity of the shear zone intersection with the surface. This turns out to be an extremely active region (see Fig. 2) with strong vertical velocities.

RESULTS

Haro Strait is a wild and exciting place to do oceanography. The frontal convergences appear on the surface as regions of large waves, boils, swirls, and debris. Even in calm conditions, surface waves are amplified and break, resulting in subsurface bubble clouds that form a distinctive acoustic target. Vertical velocities can reach 50 cm/s and transport surface water and bubbles down to 100m. During summer the convergence region originates as a flow separation at a nearby point after which its most dynamic portion moves offshore into the deeper waters in the center of Haro Strait and is accompanied by instability and mixing. Acoustic measurements of the flow field can be combined with echo-sounding measurements of bubbles drawn down in the convergence. The front has a slope of ~0.1 with the overlying water moving generally north at speeds of ~0.2m/s while the underlying and denser flow, forming the primary transport in the Strait moves south at a speed of 0.7 m/s (Figure 1). As might be predicted, this turns out to be the region subject to instability and is associated with intense vertical

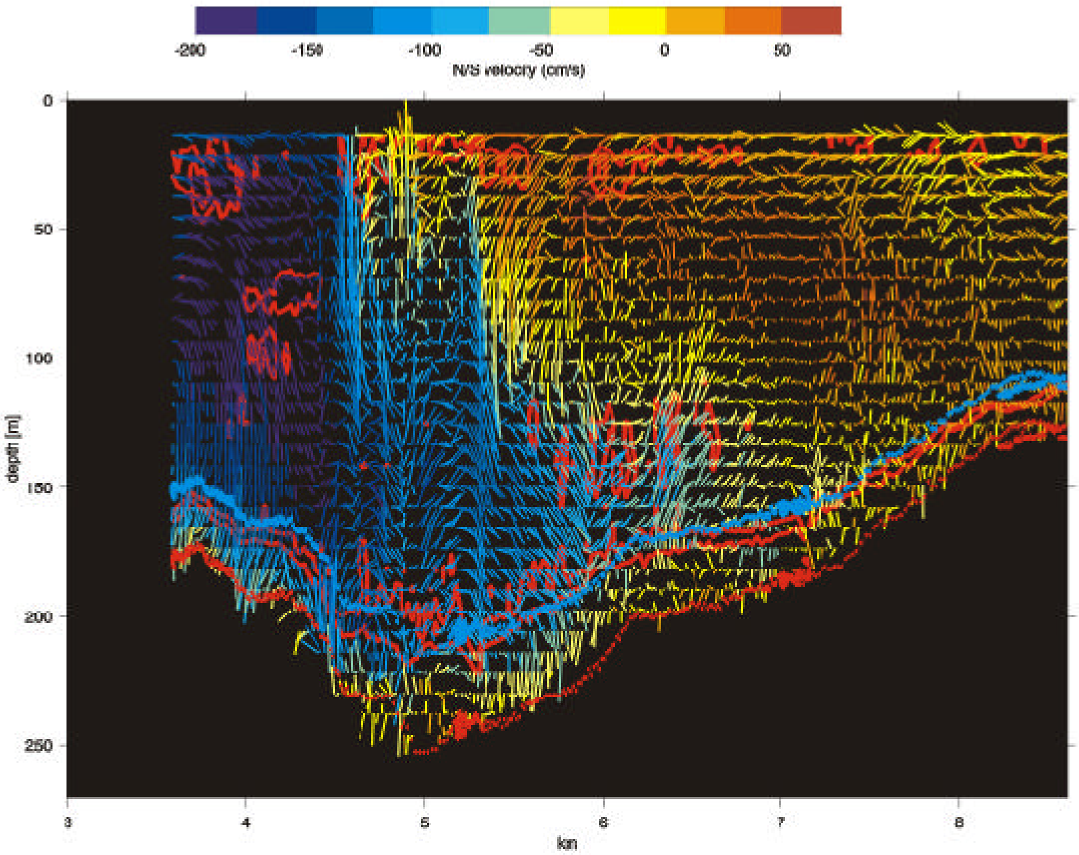

Figure 2: Combination of N/S velocities (colour) with E/W and vertical velocities (stickplot) for the transect shown in the previous figure. Areas of high backscatter intensity are indicated by irregular regions outlined in red. The large scale coherent motions involving strong vertical currents motivate an explanation in terms of the tilting of vortex lines associated with separated shear layer.

exchanges. The observations (Figure 2) show that, even though the flow separation around the island is initially associated with a strong vertical vorticity component, as it evolves the current structure becomes 3-dimensional with strong vertical currents (Figure 2). These results have motivated an explanation that accounts for the tilting of the initially vertical vorticity by the transverse density gradient, thus leading to the very intense vertical currents that draw bubble clouds down to >130m (Figure 3). These detailed measurements of frontal dynamics can be placed in perspective with the larger scale modeling of two layer exchange. The new diagnostic theory (Pawlowicz & Farmer, 1998), shows that changes in the T-S characteristics along the strait are directly related to horizontal transport. Averaged layer transport of some 10^5 m^3/s is matched by an equivalent amount of vertical mixing. This value varies by some 30% over the spring/neap cycle over which observations were taken.

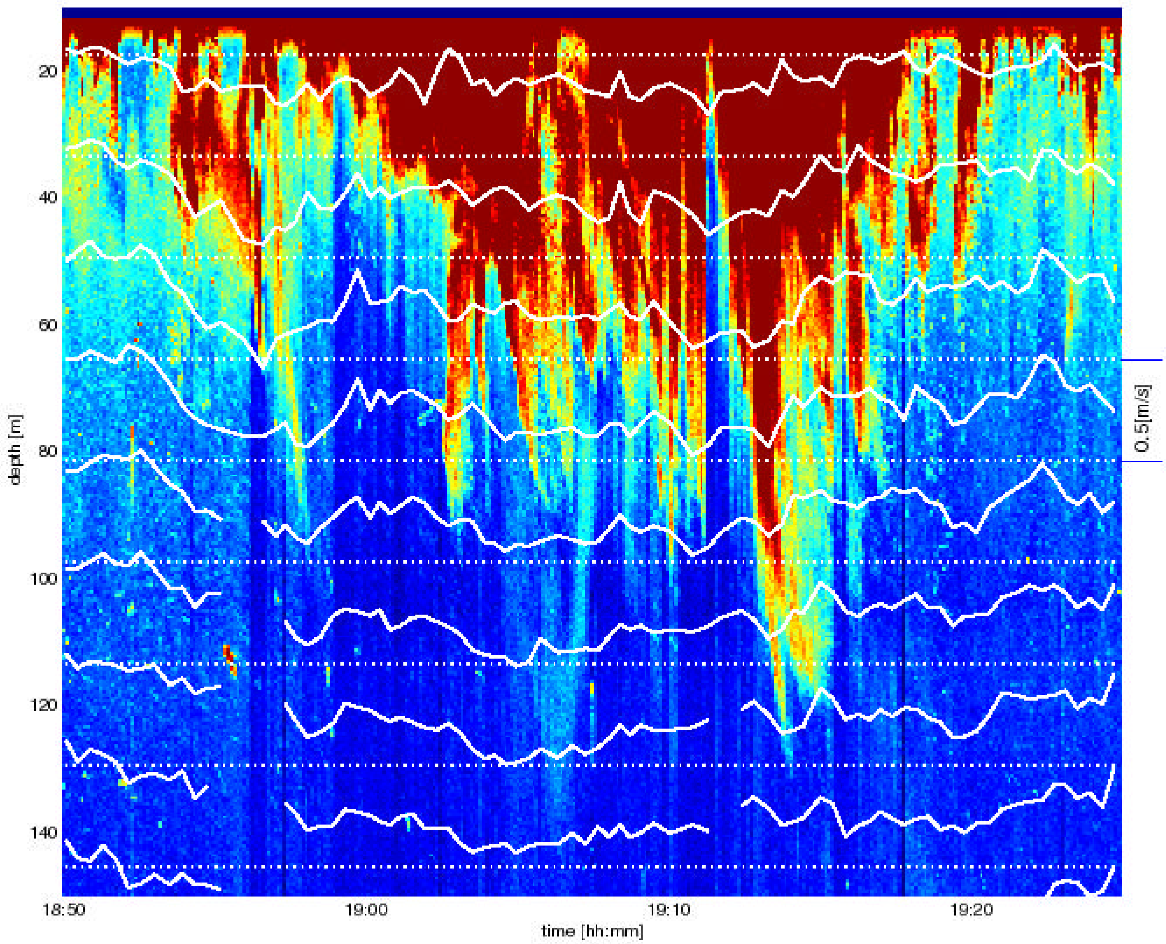

Figure 3: Echo-sounding of bubble clouds being drawn down in the vicinity of the front, with vertical velocities derived from ADCP superimposed. Bubbles, created by the breaking of small waves amplified by the current shear, even in the absence of wind, are drawn down well over a hundred metres before disappearing into solution. Vertical currents can reach 50 cm/s. in the overturns which account for intense mixing in Haro Strait.

IMPACT/APPLICATIONS

Quantifiable estimates of mixing have been made in the Haro Strait region, which controls the estuarine circulation in the waters north of Washington State. Such numbers have not previously been available. The work also shows that frontal mixing mechanisms are very strong in this area, and can rapidly move surface water down to 100m or below within a few minutes. The locations of intense vertical mixing are generally repeatable from tide to tide, hence they represent robust (and therefore probably understandable) features of the circulation. Mixing is highly localised in areas where the frontal structure is shallow enough to support instability. Since very large numbers of bubbles are brought down to great depths (~100m) on each tide, our observations suggest the possibility that such fronts can serve to reoxygenate the exchanged water mass.   Such fronts will also play a role in the concentration of surface pollutants such as spilled oil, as well as having implications for biological activity in this area.

RELATED PROJECTS

This project is closely related to the simultaneous acoustic tomography study in Haro Strait carried out by MIT and WHOI (Schmidt et al 1996), acoustic scattering and propagation measurements carried out by U.Victoria, and AUV measurements of the tidal front carried bout by MIT.

REFERENCES

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